(19) Europäisches Pat ntamt
Europ an Patent Offic
Office uropéen d s br vets

(11) EP 1 113 250 A1

(12) EUROPEAN PATENT APPLICATION

(43) Date of publication:
04.07.2001 Bulletin 2001/27

(51) Int Cl.7: G01J 4/04, G01M 11/00

(21) Application number: 00125089.3

(22) Date of filing: 17.11.2000

(84) Designated Contracting States:
AT BE CH CY DE DK ES FI FR GB GR IE IT LI LU MC NL PT SE TR
Designated Extension States:
AL LT LV MK RO SI

(71) Applicant: Agilent Technologies Inc.,
A Delaware Corporation
Palo Alto, CA 94306-2024 (US)

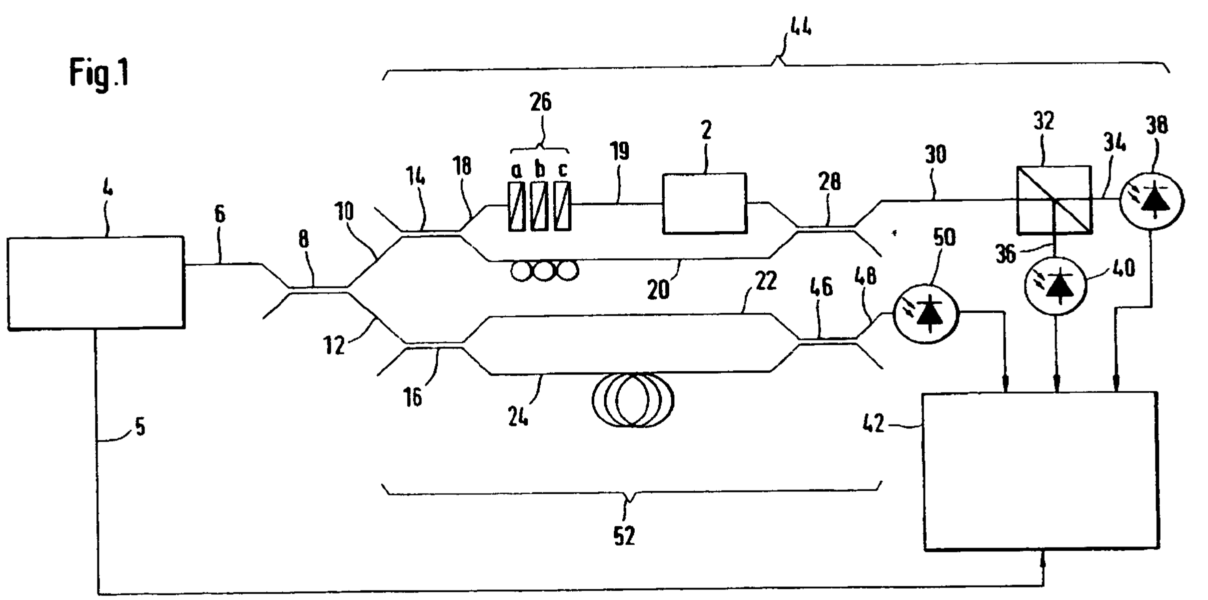
(72) Inventor: Rosenfeldt, Harald
20251 Hamburg (DE)

(74) Representative: Barth, Daniel et al
c/o Agilent Technologies Deutschland GmbH,
Herrenbergerstrasse 110
71034 Böblingen (DE)

(54) Method and apparatus for determining the polarisation mode dispersion of an optical device

(57) A method and an apparatus for determination of properties, e.g. of elements of the Jones matrix, of an optical device under test, comprising the steps of: generating a coherent light beam, splitting the light beam into a first light beam and a second light beam, coupling the first light beam with a given initial polarization into the optical device under test, letting the second light beam travel a different path as the first light beam, superimposing the first light beam and the second light beam to generate interference between the first light beam and the second light beam in a resulting superimposed light beam, splitting the superimposed light beam into a third light beam polarization dependent and a fourth light beam, continuously detecting the power of the third and the fourth light beam as a function of frequency when tuning the frequency of the coherent light beam from a minimum to a maximum of a given frequency range, deriving transmissive properties, e.g. elements of the Jones matrix, from the frequency dependency of the detected power.

Fig.1



SUMMARY OF THE INVENTION

[0011] It is an object of the invention to provide an improved determination of properties of an optical device under test, and preferably to provide starting values for calculating PMD allowing to avoid at least some of the aforementioned problems. The objects are solved by the independent claims.

[0012] An advantage of the present invention is the possibility of deriving transmissive properties, e.g. the PMD of the device under test (DUT) just by determining the elements of the Jones matrix of the DUT without need to make use of an expensive polarimeter, and the possibility of simultaneously measuring the chromatic dispersion of the DUT. Moreover, it is possible to derive additional information from the derived Jones Matrix of the DUT, since the Jones matrix contains also information about the principle states of polarization (PSP) and the polarization dependent loss (PDL) of the DUT. So, all the above-mentioned problems in the prior art can be avoided by the present invention.

[0013] The term "coherent" in this application means that the coherence length of the light beam is larger than the difference of lengths of the paths of the first and second and the fifth and sixths light beams, respectively.

[0014] In a preferred embodiment of the invention, the apparatus contains a first Mach-Zehnder interferometer whereby a polarization setting tool is placed in the measurement arm, so that the laser light couples into the DUT with a defined polarization. This direction of polarization is then defined as the x-axis of the coordinate system of the Jones matrix calculus. Accordingly, the first two elements of the Jones matrix can easily be derived. In a second run of the inventive method, the other two elements of the Jones matrix are derived with the same interferometer by changing the direction of polarization of the light beam incident on the DUT. It is preferred for easy evaluation of the results to change the polarization to a polarization orthogonal with respect to the former polarization. In this respect, it is further preferred that the initial polarization is linear and the changed polarization is changed by 90° with respect to the initial polarization.

[0015] In another preferred embodiment, there is a second Mach-Zehnder interferometer parallel to the first one. In this second interferometer the same coherent laser beam of the laser source is coupled in by a beam splitter before these two interferometers. With the help of the second interferometer, which is a reference interferometer without an optical device in its measurement arm, any non-linearities in the detected powers of the resulting beams of the first interferometer caused by a non-linearity in the scanning velocity when scanning the frequency of the laser frequency can be eliminated.

[0016] Other preferred embodiments are shown by the dependent claims.

[0017] It is clear that the invention can be partly or entirely embodied or supported by one or more suitable software programs, which can be stored on or otherwise provided by any kind of data carrier, and which might be executed in or by any suitable data processing unit.

BRIEF DESCRIPTION OF THE DRAWINGS

[0018] Other objects and many of the attendant advantages of the present invention will be readily appreciated and become better understood by reference to the following detailed description when considering in connection with the accompanied drawings. The components in the drawings are not necessarily to scale, emphasizes instead being placed upon clearly illustrating the principles of the present invention. Features that are substantially or functionally equal or similar will be referred to with the same reference sign(s).

Fig. 1 shows a schematic illustration of an embodiment of the apparatus of the invention;

Fig. 2 shows two graphs comparing PSP group delay with DGD; and

Fig. 3 shows two graphs comparing PSP group delay with DGD without a device under test.

DETAILED DESCRIPTION OF THE INVENTION

[0019] Referring now in greater detail to the drawings, Fig. 1 shows a schematic illustration of a preferred embodiment of an apparatus 1 for interferometric determination of the frequency-dependent Jones matrix of a two port optical transmission device under test (DUT) 2, according to the present invention. The apparatus 1 according to Fig. 1 and the respective method as described in the following is contemplated by the inventor as the best mode of carrying out the invention. By means of the apparatus 1 shown in Fig. 1 the DUT 2, which is an optical component and can be a fiber, a Bragg-grating or any other optical component or even air, is to be characterized in terms of its chromatic dispersion and its PMD.

[0020] The apparatus 1 comprises as a signal source a tunable laser 4, which can be continuously tuned in respect of frequency. The laser 4 emits a coherent laser beam 6. The laser beam 6 is coupled into a first beam splitter 8 which

[0031] Generally, the Jones matrix describes a birefringent element that at an optical frequency ω has two main axes with which two differential group delays $\tau_\pm$ can be associated. The associated input and output polarization states are also referred to as main states or principal states of polarization (PSP). Now, using U(ω) the differential group delay (DGD) between the principal axes is to be det rmined. If $\vec{E}_{a\pm}$ and $\vec{E}_{b\pm}$ are the (still unknown) principal states at the input and the output of DUT 2, respectively, it is possible to establish the following relationship:

$$\vec{E}_{b\pm} = e^{+j\tau\pm\omega} \cdot U \cdot \vec{E}_{a\pm}$$

[0032] $\vec{E}_{a\pm}$ and $\vec{E}_{b\pm}$ are to be standardized in such a way that their mean phase disappears: $Im\{E_x \cdot \vec{E}^*_y\}=0$. The principal states are in a first approximation independent of frequency. Therefore the following applies:

$$\frac{d\vec{E}_{b\pm}}{d\omega} = j\tau_\pm \cdot U \cdot \vec{E}_{a\pm} + e^{j\tau_\pm\omega} \cdot \dot{U} \cdot \vec{E}_{a\pm} \overset{!}{=} 0$$

[0033] Conversion gives a generalized eigen-value problem:

$$\dot{U} \cdot \vec{E}_{a\pm} = j \cdot e^{j\tau\pm\omega} \cdot \tau_\pm \cdot U \cdot \vec{E}_{a\pm}$$

[0034] The eigen-values give:

$$\lambda_\pm = j \cdot e^{j\tau\pm\omega} \cdot \tau_\pm$$

[0035] Taking the magnitude of the eigen-values, it is possible to calculate the differential group delay of the two principal states, and thus the DGD:

$$\tau_\pm = |\lambda_\pm| \ , \ DGD = \tau_+ - \tau$$

[0036] In order to be able to determine the Jones Matrix U, it is necessary (see above) to carry out two partial measurements with respectively orthogonal input polarizations E_{a1} and $\vec{E}_{a2}$ of the polarized laser beam 19. If those two input polarizations are used as base vectors for the Jones representation, then that would correspond to the following input vectors:

$$\vec{E}_{a1} = \begin{pmatrix} 1 \\ 0 \end{pmatrix} \cdot E_0 \quad , \quad \vec{E}_{a2} = \begin{pmatrix} 0 \\ 1 \end{pmatrix} \cdot E_0$$

[0037] The corresponding output vectors read as follows:

$$\vec{E}_{b1} = \begin{pmatrix} u_{11} \\ u_{21} \end{pmatrix} \cdot E_0 \quad , \quad \vec{E}_{b2} = \begin{pmatrix} u_{21} \\ u_{22} \end{pmatrix} \cdot E_0$$

[0038] The symbols u_{mn} in that case denote the four elements of the Jones matrix. The light 20 coming from the reference arm can be described by the following Jones vector:

$$\vec{E}_r = \begin{pmatrix} \cos\varphi \cdot e^{-j\phi} \\ \sin\varphi \cdot e^{+j\phi} \end{pmatrix} \cdot e^{-j\tau_r\omega} \cdot E_0$$

[0046] Fig. 3 shows a measurement with the above-described method without DUT 2 in the apparatus of Fig. 1:

[0047] In Fig. 3 the upper plot shows the group delay of the two principal axes. The abscissa shows the wavelength in nm and the ordinate shows the group delay in ps. The lower plot shows the difference between the two group delays, the DGD in ps over the wavelength in nm. As expected the DGD is closer to zero. Marked deviations from the ideal value however can be seen, which permits an assessment of the measurement accuracy of the apparatus 1 of the present invention of a few pico-seconds.

Claims

1. A method of determination of properties of an optical device under test (2), comprising the steps of:

   - generating a coherent light beam (6),
   - splitting the light beam (6) into a first light beam (18, 19) and a second light beam (20),
   - coupling the first light beam (18, 19) with a given initial polarization into the optical device under test (2),
   - letting the second light beam (20) travel a different path as the first light beam (18, 19),
   - superimposing the first (18, 19) and the second light beam (20) to generate interference between the first light beam (18, 19) and the second light beam (20) in a resulting superimposed light beam (30),
   - splitting the superimposed light beam (30) polarization-dependent into a third light beam (34) and a fourth light beam (36),
   - continuously detecting the power of the third light beam (34) and the fourth light beam (36) as a function of frequency when tuning the frequency of the coherent light beam (6) from a minimum to a maximum of a given frequency range, and
   - deriving transmissive properties of the optical device under test from the frequency dependency of the detected powers.

2. The method of claim 1, further comprising the step of:

   - deriving elements of the Jones matrix for the optical device under test from the frequency dependency of the detected powers.

3. The method of claim 1 or 2, further comprising the steps of:

   - changing the initial polarization of the first light beam (18, 19) with respect to said given initial polarization into a changed polarization,
   - performing the steps of claim 1 a second time with said changed polarization.

4. The method according to claim 1 or any one of the above claims, further comprising the step of:

   - polarizing the first light beam (18, 19) after splitting the coherent light beam (6).

5. The method according to claim 1 or any one of the above claims 2 - 3, further comprising the step of:

   - polarizing the coherent light beam (6) before splitting it.

6. The method according to claim 3 or any one of the above claims 4 - 5, further comprising the step of:

   - changing the initial polarization of the first light beam (18, 19) into an orthogonal polarization.

7. The method according to claim 3 or any one of the above claims 4 - 6, further comprising the step of:

as a function of frequency when tuning the frequency of the coherent light beam (6) from a minimum to a maximum of a given frequency range,

a second power detector (38) in said fourth path for continuously detecting the power of the fourth light beam (36) as a function of frequency when tuning the frequency of the coherent light beam (6) from a minimum to a maximum of a given frequency range,

an evaluation unit for deriving transmissive properties of the optical device under test (2) from the frequency dependency of the detected powers.

12. The apparatus of claim 11,
comprising an evaluation unit for deriving elements of the Jones matrix of the optical device under test (2) from the frequency dependency of the detected and converted powers.

13. The apparatus of claim 11 or 12,
wherein the first beam splitter (14), the second beam splitter (28), the polarization beam splitter (PBS) (32), the first power detector (38), and the second power detector (38) provide a first Mach-Zehnder interferometer (44).

14. The apparatus according to claim 11 or any one of the above claims 12-13,
further comprising a polarization setting tool (26) positioned in said first path for polarizing the first light beam (18, 19) in the given initial polarization.

15. The apparatus of claim 14,
wherein the polarization setting tool (26) is positioned in the path of the coherent light beam (6) before the first beam splitter (14).

16. The apparatus according to claim 13 or any one of the above claims 14-15,
wherein the polarization setting tool (26) linearly polarizes the respective beam (6; 18).

17. The apparatus according to claim 11 or any one of the above claims 12-16, further comprising:

- a third beam splitter (8) in the path of the coherent light beam (6) for splitting the coherent light beam (6) into a first initial light beam (10) travelling a first initial path and a second initial light beam (12) travelling a second initial path,

- a fourth beam splitter (16) in said second initial path for splitting the second initial light beam (12) in a fifth light beam (22) travelling a fifth path and a sixth light beam (24) travelling a sixth path,

- a fifth beam splitter (46) in said fifth and said sixth path for superimposing the fifth (22) and the sixth light beam (24) after each light beam (22, 24) has traveled a different path, to generate interference between the fifth (22) and the sixth light beam (24) in a resulting superimposed light beam (48) travelling a second resulting path,

a third power detector (50) in said second resulting path for continuously detecting the power of the resulting superimposed light beam (48) as a function of frequency when tuning the frequency of the coherent light beam (6) from a minimum to a maximum of a given frequency range, an output of the power detector (50) is connected via analog/digital-converter (42) with the evaluation unit for detecting any non-linearity in a tuning gradient frequency when tuning the frequency of the coherent light beam (6) from the minimum to the maximum of the given frequency range, and in case evaluation unit is detecting any non-linearity, the evaluation unit is using said detected non-linearity information to compensate effects on the detected powers of the third (34) and the fourth light beam (36) caused by said non-linearity.

18. The apparatus according to claim 11 or any one of the above claims 12-17, further comprising:
a tunable light source (4) for generating the coherent light beam (6).

19. The apparatus according to claim 11 or any one of the above claims 12-18, further comprising:

an analog/digital-converter (ADC) (42) connected with an output of the first detector (38) and connected with an output of the second detector (40) for converting the received analog data into digital data,

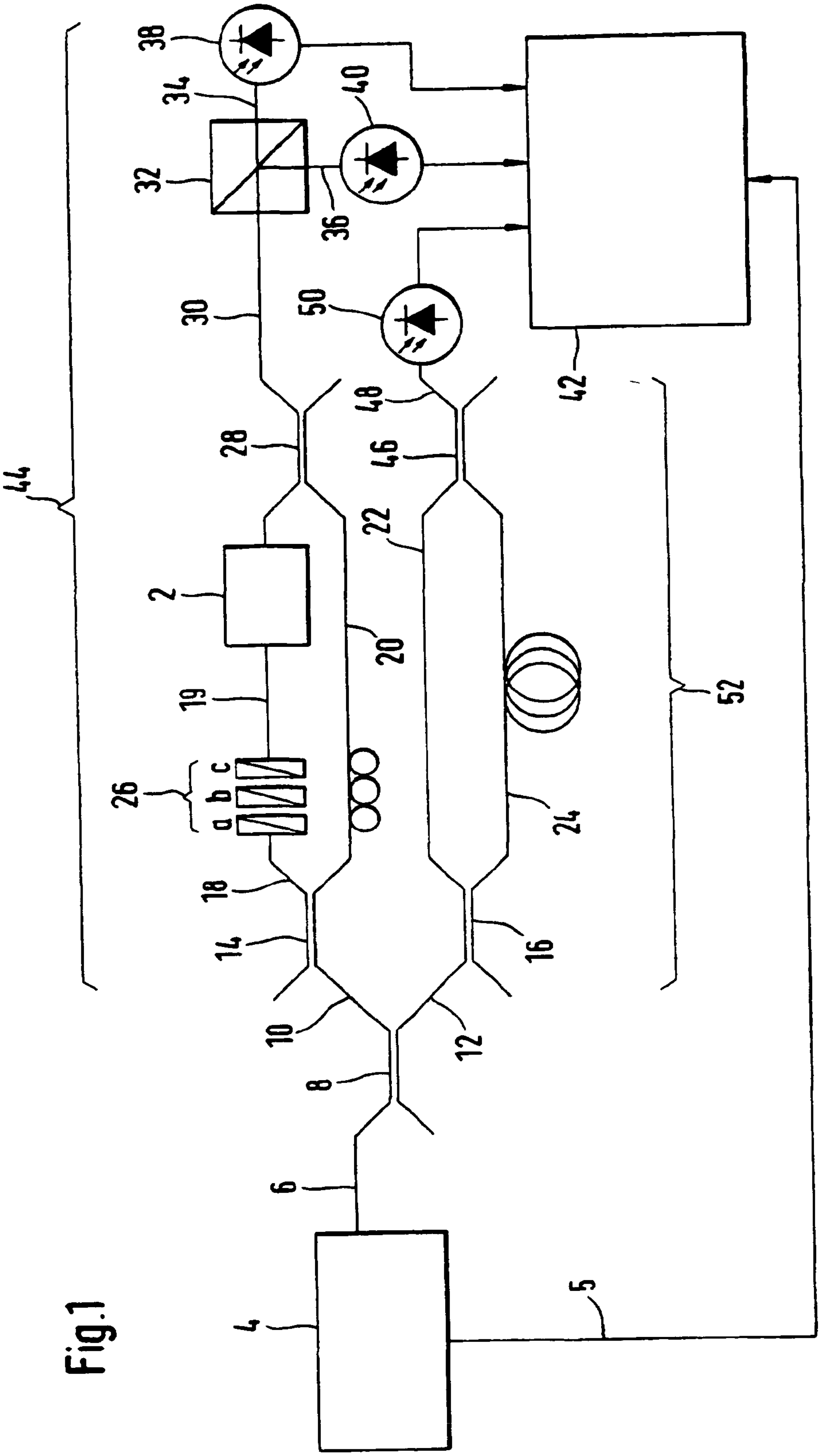
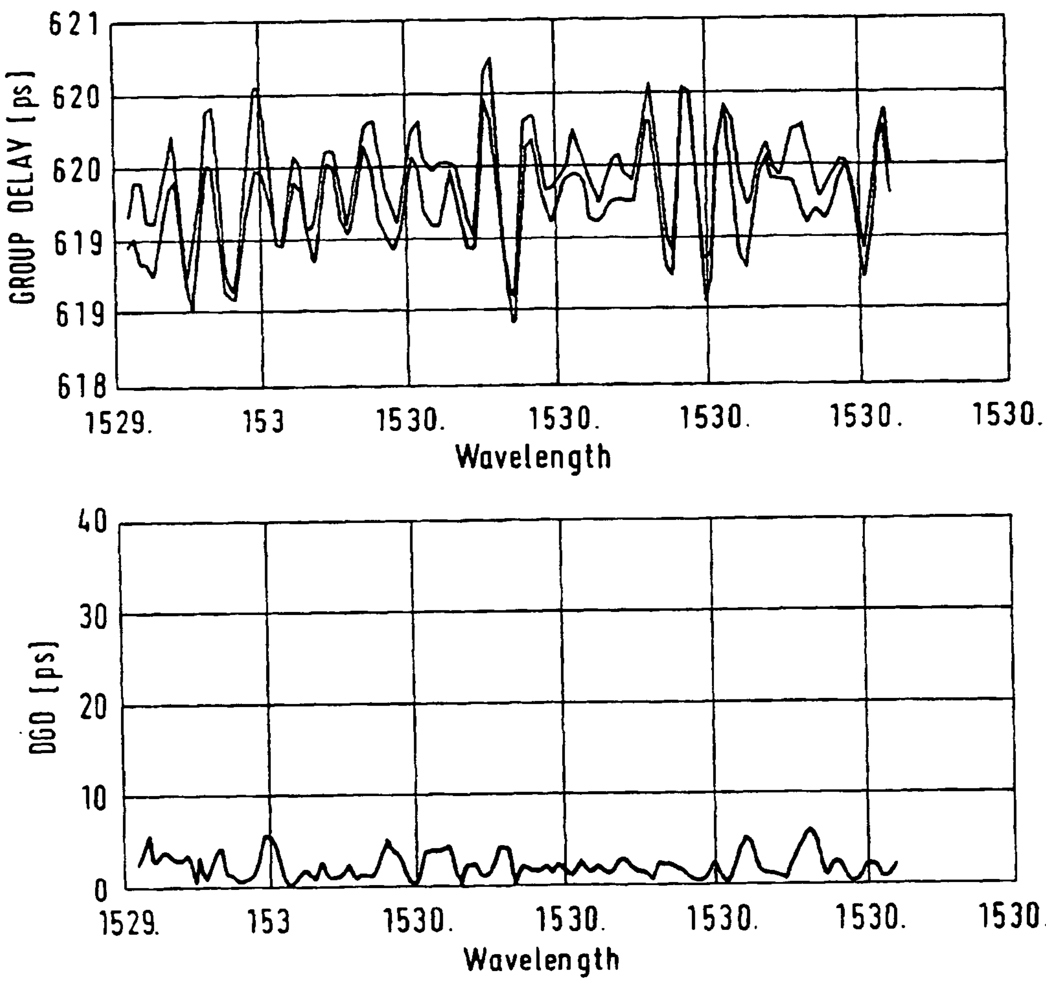

38
34
40
32
36
30
50
48
42
28
46
44
22
2
20
19
52
26
a b c
24
18
14
16
10
12
8
6
5
4

Fig.1

Fig.3


621
620
620
619
619
618
GROUP DELAY [ps]
1529.
153
1530.
1530.
1530.
1530.
1530.
Wavelength
40
30
20
10
0
DGD [ps]
1529.
153
1530.
1530.
1530.
1530.
1530.
Wavelength

ANNEX TO THE EUROPEAN SEARCH REPORT ON EUROPEAN PATENT APPLICATION NO. EP 00 12 5089

This annex lists the patent family members relating to the patent documents cited in the above-mentioned European search report.
The members are as contained in the European Patent Office EDP file on
The European Patent Office is in no way liable for these particulars which are merely given for the purpose of information.

24-04-2001

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
US 5852496 A	22-12-1998	FR 2745082 A	22-08-1997
		GB 2310281 A,B	20-08-1997
US 5717489 A	10-02-1998	JP 3131144 B	31-01-2001
		JP 9264814 A	07-10-1997
		DE 19712768 A	06-11-1997

EPO FORM P0459

For more details about this annex : see Official Journal of the European Patent Office, No. 12/82